INVESTIGATION 5-A

Testing the Law of Conservation of Energy

TARGET SKILLS
- Predicting
- Performing and recording
- Analyzing and interpreting

When scientists set out to test an hypothesis or challenge a law, they often use the hypothesis or law to make a prediction and then test it. In this investigation, you will make a prediction based on the law of conservation of energy.

Problem

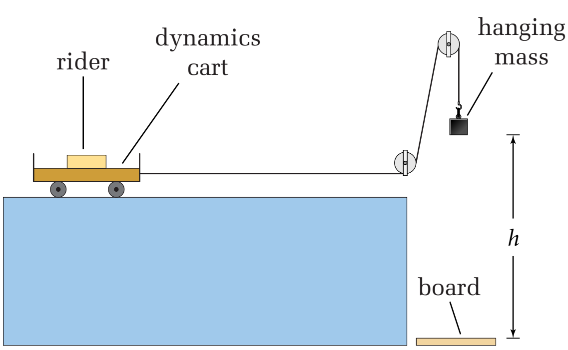
To perform a test of the law of conservation of energy

Equipment

- dynamics cart
- balance capable of measuring a mass of 1 to 2 kg
- 2 pulleys
- retort stand and clamps for the pulleys
- board (or similar material) to protect the floor from dropped masses
- metric measuring tape
- selection of masses, including several that can be suspended on a string
- stopwatch or photogate timers
- string about 4 m long

Procedure

1. Determine the mass of the dynamics cart.
2. Select a mass to be the rider and a mass to be the hanging mass. Decide on the height of the hanging mass above the board.
3. Set up the apparatus on a long desktop, as shown in the diagram.



4. Using the law of conservation of energy, calculate the expected speed of the cart and the hanging mass just before the mass strikes the board. If the cart is to be released from rest, determine the average speed of the system and then the predicted time interval for the hanging mass to drop to the board.
5. With the entire apparatus in place, hold the cart still. Release the cart and measure the time taken for the hanging mass to reach the board. Be sure to catch the cart before it hits the lower pulley.
6. Repeat the measurement several times and average the results.
7. Perform several trial runs with a different pair of masses for the cart and the hanging mass.

Analyze and Conclude

1. Prepare a table to show all of your data, as well as your calculations for the final speed, average speed, and the time interval.
2. What is the percent difference between the time as predicted by the law of conservation of energy and the measured average time?
3. Based on the precision of the timing devices, what range of experimental error would you expect in this investigation? How does this range compare with the percent difference determined in question 2?
4. Do the results of this investigation support the law of conservation of energy?

Apply and Extend

5. Which part of this investigation caused the greatest difficulty? Provide suggestions for overcoming this difficulty.
6. List some of the sources of error in this investigation and suggest how these errors might be reduced.

Work and Energy Change with a Variable Force

Until now, you have assumed that the force in the expression for work was constant. Quite often, however, you must deal with situations in which the force varies with the position, as shown in part (A) of Figure 5.6.

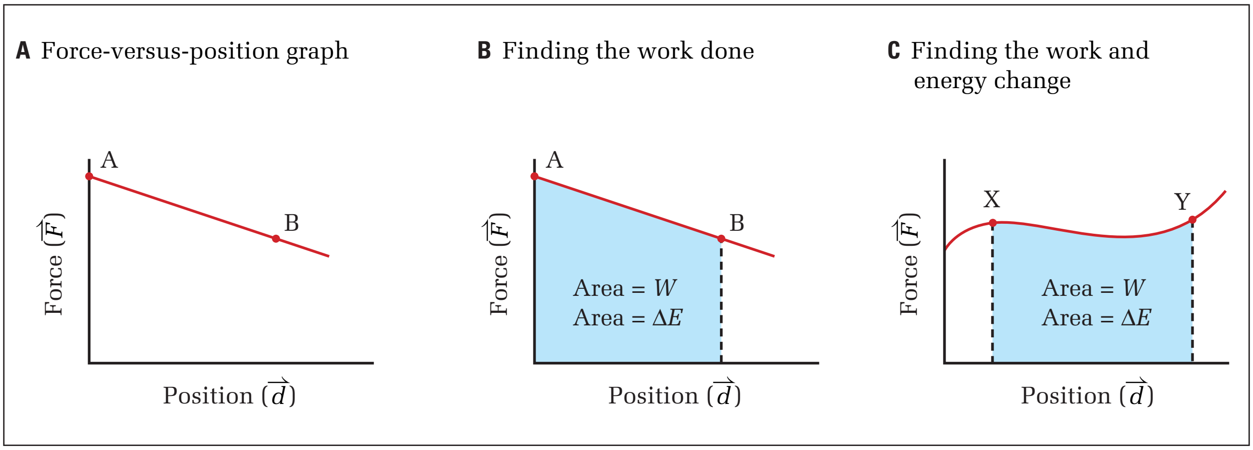


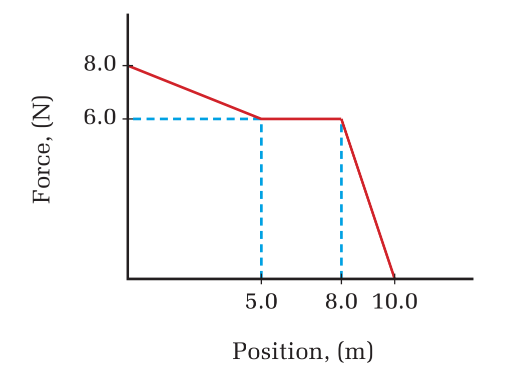
Figure 5.6 The work done, or the change in energy, is equal to the area under the graph

Since work is defined as the product of force times the displacement over which the force acts, then work must be equivalent to the graphical area under a graph of force versus position (displacement is a change in position). Such an area is illustrated in parts (B) and (C) of Figure 5.6. In the simplest cases, the graphical area forms a figure for which the area can be readily determined, as shown in the following sample problem.

SAMPLE PROBLEM

Work Done by a Variable Force

The graph shows the variation of applied force with position. Determine the work done by the force and the total energy change due to that force.



Conceptualize the Problem

- The problem involves a graph of *force versus position*.
- The graphical *area under the curve* provides the *work* done.
- *Work* is equal to the total *change in energy*.

Identify the Goal

- The work, W, done by the applied force
- The total energy change ΔE_{total}, due to the force

Identify the Variables and Constants

Known	Unknown
graph of force versus position	W
	ΔE_{total}

Develop a Strategy

Divide the graphical area under the curve up into recognizable shapes.

Determine the area of each region.

The region from the origin to 5.0 m is a trapezoid.

Area of trapezoid

A = (average of parallel sides)(distance between them)

$$A = \left(\frac{8.0\ \text{N} + 6.0\ \text{N}}{2}\right)5.0\ \text{m}$$

$$A = 35\ \text{N} \cdot \text{m}$$

$$A = 35\ \text{J}$$

The region from 5.0 m to 8.0 m is a rectangle.

Area of rectangle = (base)(height)

$$A = (3.0\ \text{m})(6.0\ \text{N})$$

$$A = 18\ \text{N} \cdot \text{m}$$

$$A = 18\ \text{J}$$

The region from 8.0 m to 10.0 m is a triangle.

$$\text{Area of triangle} = \frac{1}{2}(\text{base})(\text{height})$$

$$A = \frac{1}{2}(2.0\ \text{m})(6.0\ \text{N})$$

$$A = 6.0\ \text{N} \cdot \text{m}$$

$$A = 6.0\ \text{J}$$

Find the total area.

$$\text{Total area} = 35\ \text{J} + 18\ \text{J} + 6.0\ \text{J}$$

$$\text{Total area} = 59\ \text{J}$$

$$W = \Delta E_{total}$$

$$\Delta E_{total} = 59\ \text{J}$$

The work done, and therefore the total change in energy, is 59 J.

Validate the Solution

From examination of the graph, an average force would seem to be approximately 5 N and acts over 10 m. An approximate value for the work done would be 50 N. The answer is not far from this value.

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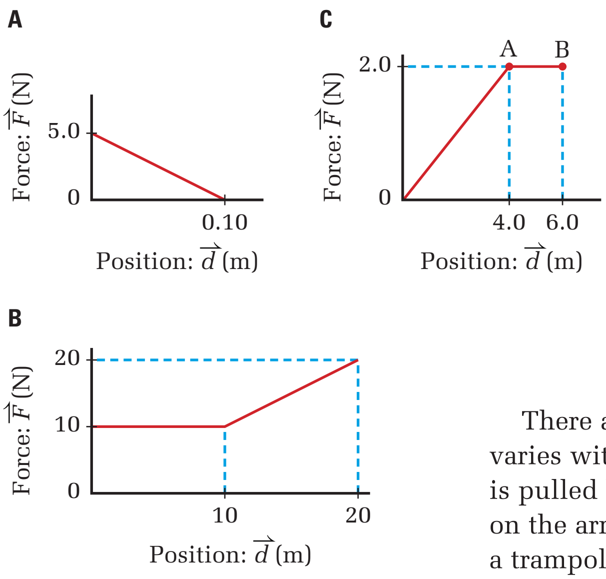
PRACTICE PROBLEMS



13. Calculate the work done by the force depicted in part (A) of the diagram.

14. Determine the magnitude of the energy change produced by the force illustrated in part (B) of the diagram.

15. The force shown in part (C) of the diagram acts horizontally on a 2.0 kg cart, initially at rest on a level surface. Determine the speed of the cart at point A and at point B.

There are many examples in which the applied force varies with displacement. The more an archery bow string is pulled back, the greater the force that the string can exert on the arrow. Force increases with the amount of stretch in a trampoline. Springs are interesting in that they can exert forces when they are stretched or compressed, and the amount of force depends on the amount of extension or compression. You will study this type of relationship in the next section of this chapter.

5.1 Section Review

1. K/U Give examples that were not used in the text to show that no work is done by an applied force that is perpendicular to the direction of the motion of the object.

2. I If the force of friction is constant, prove that the stopping distance of a car on a level road varies directly with the square of the initial speed.

3. K/U When developing the equation for gravitational potential energy, why was it necessary to assume that the mass was rising at a constant speed?

4. I Prove the expressions for gravitational potential energy and kinetic energy have units that are equivalent to the newton · metre.

5. MC The absolute temperature of a gas is a measure of the average kinetic energy of the gas atoms or molecules. What happens to the average speed of these particles when the absolute temperature of the gas is doubled?

6. C

(a) What is meant by the term "isolated system"?

(b) Describe an example of a system that could be considered as being isolated.

(c) Explain why this system is probably not completely isolated.

7. MC A variable force, $\vec{F}$, acts through a displacement, Δd. The magnitude of the force is proportional to the displacement, so $F = k\Delta d$, where k is constant.

(a) Sketch a graph of this force against position up to position x.

(b) According to the equation, what is the value of the force at x?

(c) Determine an expression for the work done by this force in terms of k and x.